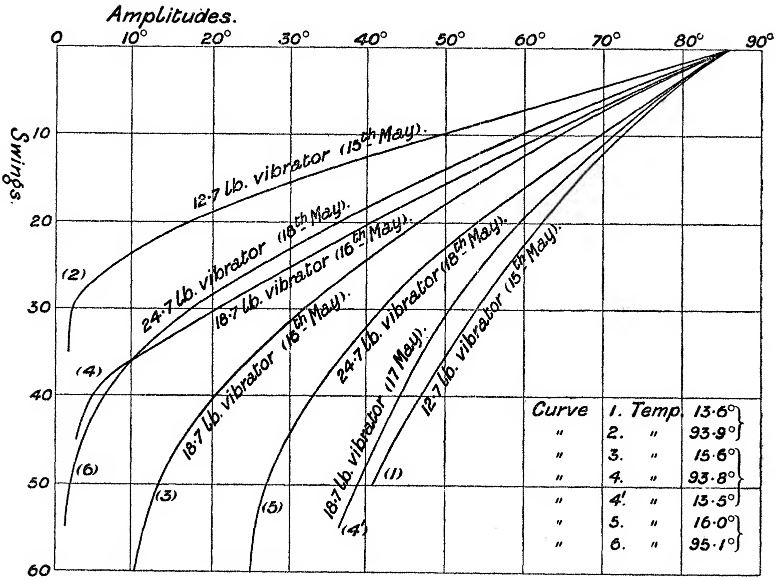
DIAGRAM VI.—Soft iron.



the successive operations have had a considerable effect on the behaviour of the wire; and experiments are being made to elucidate this effect as far as possible.

Some other points of interest which were observed in these experiments are reserved for further investigation in a continuation of the work now in progress.

"On the Connection between the Electrical Properties and the Chemical Composition of Different Kinds of Glass. Part II." By Professor ANDREW GRAY, LL.D., F.R.S., and Professor JAMES J. DOBBIE, M.A., D.Sc. Received May 25,—Read June 21, 1900.

In a former paper* we described experiments on the electrical qualities of specimens of glass of which the chemical composition was determined by analysis. Results were given for a lead-potash glass made by Messrs. Powell and Sons, of London, a lead-potash glass made by Messrs. Schott and Co., of Jena, a barium glass, and a zinc-soda glass ("Jena glass"), both made by Messrs. Schott and Co. These

* 'Roy. Soc. Proc.,' No. 390, April 20, 1898.

specimens are referred to in the paper by the numbers XXI—XXIV.

We have now to communicate the results of some further experiments, the object of which was to throw light on various points which had arisen in connection with the previous experiments, and to afford information as to whether the resistance or capacity of the glass was affected by the process of annealing, or varied with time. The specimens here referred to are numbered XXV—XXXII, and were all made, as nearly as possible, according to a previously prescribed composition, and in the form of flasks, with long thick-walled necks, adapted for experiments by the direct-deflection method formerly employed. Full particulars of the different specimens are given in Table I below.

The method of experimenting and the method employed were the same as those described in our former paper. The chief sources of error which had to be guarded against were, as before, surface conduction, due to moisture on the surface of the glass, and leakage at other parts of the apparatus, due to the want of perfect insulation. The most careful watch was kept throughout the experiments against the possibility of inaccuracy from these causes, and tests were made in connection with each determination to make sure that everything was working correctly.

The Resistance Experiments.

Only a few days before the meeting of the Royal Society at which the paper referred to above was read, a rough test was made of the resistance of a flask (XXVII below) made for us by Messrs. Powell and Sons, which had approximately the same composition as Specimen XXI, the potash, however, being replaced by soda. It will be seen by a reference to our former table of results, that XXI was a lead-potash glass of very high specific resistance, certainly above 18000×10^{10} at 130° C. It was anticipated from our experiments that the substitution of soda for the potash in this glass would very greatly diminish the specific resistance, and it was stated when the paper was read that this conclusion had been verified. More accurate determinations made since that time have confirmed this result, as will be seen by a comparison of Table I with the table given in the former paper. While XXI had the resistance at about 130° C. quoted above, the specific resistance of XXVII at about the same temperature was only 136×10^{10}; so that the substitution of soda for potash in the composition of the glass diminishes the resistance of the glass to $\frac{1}{130}$ of its former amount.

The influence of the substitution of soda for potash is still more clearly brought out by a comparison of XXIX with XXXI, and XXX with XXXII. Specimens XXIX and XXX are lead-potash glasses,

XXX and XXXII lead-soda glasses, in which the amount of soda is nearly equivalent chemically to the potash in XXIX and XXX respectively. Reference to Table I will show that in both cases the potash glasses have very much higher resistances than the soda glasses.

Both XXI and XXVII were lead glasses; but in the previous paper a glass was discussed which was made by Messrs. Schott and Co., and was composed mainly of barium oxide and alumina in combination with silica and boron trioxide. This, which we shall call the Jena barium glass, had a very high resistance, one quite unmeasurable, indeed, within the range of temperatures covered by the experiments. Moreover, it was found that the inductive capacity in a plate of this glass was exceedingly low, and that the glass showed little or no effects of dielectric polarisation.

It was thought that it might be of interest to find whether the high resistance of this glass was associated with the presence of the large percentage of barium oxide. Accordingly, further experiments have been made on flasks of barium-potash glass manufactured by Messrs. Powell and Sons. This glass is numbered XXVIII of Table I. Its resistance is very low in comparison with that of either the lead-potash glass or the Jena barium glass, which, however, it must be remembered contained no potash. It was found to be subject to a somewhat rapid disintegration of its surface, and it probably differed in physical constitution from the Jena glass. The Jena glass, moreover, contains a considerable quantity of boron trioxide and alumina, which are absent from the glass made by Messrs. Powell. The presence in glass, however, of a considerable percentage of potash with lead is, as shown by XXIX and XXX, consistent with a high specific resistance.

It is interesting also to compare XXVIII and XXVI, which contain approximately the same percentage of barium and lead oxides respectively, and are otherwise very similar. The lead glass, XXVI, contains soda, from which the barium glass, XXVIII, is free; but in spite of this, the resistance of XXVI is about three times that of XXVIII at the same temperature.

Comparison with Ordinary Glass.—Experiments were next made to test how the glasses of specially prescribed chemical composition, already experimented on, compared with the ordinary kinds of glass used in the construction of apparatus. A common lime glass, XXV, and common lead glass, XXVI, were examined. The resistances of both of these were low; that of XXV was low in comparison with the resistance of any other glass in the table.* As has been pointed out,

* It may be noticed here that the first experiments on the electrical properties of specimens of glass, which were afterwards subjected to chemical analysis, seem to be those described in Mr. T. Gray's paper, 'Roy. Soc. Proc.,' vol. 34, p. 199. The analyses of the specimens (which were of glasses used for different purposes in the arts) were made with great care by Professor Divers, of Tokio.

however, the resistance of XXVI considerably exceeded that of the barium glass, XXVIII.

Effect of Annealing.—The last four specimens mentioned in Table I (XXIX—XXXII) were experimented on to find the effect of annealing on the resistance of glass. It is well known that in most conductors, especially pure metals, the effect of annealing is to diminish the specific resistance. XXIX and XXX were specimens of Messrs. Powell's lead-potash glass. Of these, XXIX and XXXI were carefully annealed in the usual way by Messrs. Powell: XXX and XXXII were left in the unannealed state.

The results are given side by side in Table I, and show that the effect of annealing glass is very greatly to increase its specific resistance. In the case of XXX and XXXII, the lead-soda glasses, the specific resistance has been raised to three times its former value. Annealed glass is therefore a much better insulator than unannealed glass.

Variation of Resistance with Time.—The question of variation of resistance with time has been investigated by testing flasks, which had been set apart for the purpose, at intervals of about six months. The results are shown in Table II. XXI, XXVII, and XXVIII have had their resistances determined three times, and so far no change has disclosed itself. As noticed above, the surface of the glass XXVIII seems to become disintegrated in course of time; for the surface, which was originally cleaned till quite clear, has gradually acquired a milky appearance, and is now quite opaque.

The Capacity Experiments.

The specific inductive capacity of the glass of these flasks was determined by the method described in our former paper, and the results are shown in Table I. It will be seen that the specific inductive capacity of Powell's lead-soda glass, XXVII, is rather low in comparison with that of the corresponding lead-potash glass, XXI, which was about 8.

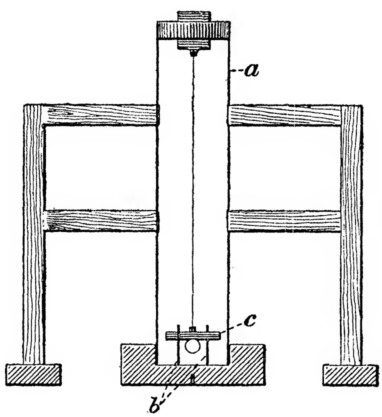
It is noteworthy, however, that the lead-soda glass was free from the dielectric polarisation effects which were so troublesome in the case of XXI. Of the glasses discussed in the present paper, XXVI, one of the ordinary glasses experimented on, was the only one that showed dielectric polarisation conspicuously.

No trouble from dielectric polarisation was experienced with Nos. XXIX—XXXII, so that annealing does not cause any marked differences in the "electric absorption" of the glass.

Measurement of Residual Twist of Glass Fibres.

The object of these experiments was to compare fibres of the glasses, on which the electrical experiments already described had been carried out, as regards imperfection of their torsional elasticity.

The figure shows a sketch of the apparatus used. A long cylindrical glass tube (a), about 23 inches in length and 2 inches in diameter, was fixed permanently in a vertical position in a wooden frame, as indicated in the diagram. A tightly-fitting cork closed the upper end of the tube, and through a narrow slit in this passed a rectangular piece of copper foil, from the centre of the lower edge of which projected a short tag of the foil. This tag was quite rigid, and carried attached to it with shellac cement the glass fibre, care being taken that the fibre was so placed that it hung vertically along the axis of the tube, when the cork was fixed in position. The lower end of the fibre was attached in a similar manner to a cross-piece, c, weighing about 1 gramme, and having a length of about $1\frac{3}{4}$ inches. The fibre was attached to the upper end of the cross, and to the lower end was fixed a small mirror.



The lower end of the glass tube fitted into a groove cut in a wooden sole-plate, capable of being rotated about a vertical axis, which coincided as nearly as possible with the axis of the tube, that is, with the position of the fibre. Two brass pins (b) were fixed vertically at two points in the sole-plate within the tube, and, projecting upwards, stood one on one side the other on the other side of the horizontal arm of the cross-piece. By turning the sole-plate round, any required twist could be given to the fibre, since the tube was held fast in its supporting frame.

A lamp and scale set in front of the mirror enabled the position of the lower end of the fibre to be observed.

After fixing the fibre and allowing the arrangement to stand undisturbed for a day or two to allow the cement to harden, the scale was placed in position with its ends at equal distances from the mirror. The zero position of the spot of light on the scale was observed, and the sole-plate turned round to give a total turning of the lower end of the fibre relatively to the upper of 360°. The couple was kept applied for thirty seconds, and then taken off gradually without any jerking of the fibre. This prevented torsional oscillation of the fibre after the removal of the couple. In fifteen seconds after the removal of the couple a reading of the position of the spot of light was taken. From this the angular deflection of the lower end of the fibre was obtained, and the angle so measured, divided by the length of the fibre, gave the residual twist.

The following table gives the results in radians per centimetre of the length of the fibre $\times 10^4$. The diameter of the fibre was found by weighing a known length of it, and calculating from the known density of the glass.

No. of specimen.	Diameter in centimetres.	Residual twist.
XXI	0·0109	2·09
XXII	0·016	1·84
XXIII	0·010	0·93
XXIV	0·0105	3·83
XXV	0·0115	7·19
XXVI	0·015	5·41
XXVII	0·0187	2·44
XXVIII	0·0105	5·52
XXIX	0·0142	0·83
XXX	0·0183	0·8
XXXI	0·0148	1·9
XXXII	0·0191	2·8

The experiments on Specimens XXI—XXVII inclusive were made in June and July, 1898, and it was then thought that there appeared to be some connection between the resistances and the residual twist of the fibres. But since XXI to XXIII were glasses whose resistances were too high for measurement, it was of course impossible to draw any numerical conclusion on the point without examining more specimens. A very little reflection, however, showed that no exact comparison was possible from this point of view, as the residual torsion was no doubt influenced in a very marked degree by the immediate previous history of the fibre. But it is noteworthy that the residual twist is very low in the case of the Jena barium glass and in Messrs. Powell's lead-potash glasses, viz., in XXIII, XXIX, XXX, and is abnormally high for the two ordinary glasses, XXV, XXVI.

It was found that for the same fibre the same twisting couple produced the same residual twist, provided the two determinations were not made in immediate succession. The rate at which the residual twist came out was very great immediately after the twisting couple had been taken off; and this rate diminished rapidly as the spot of light approached its zero position on the scale.

Chemical Composition of the Specimens of Glass.

The results of the chemical analyses made for the different specimens are stated briefly in Table I, which affords a conspectus of all the results of the experiments now described.

The following notes regarding the different specimens, containing approximate empirical formulæ for their composition, are, however, set down here.

XXV. This is an ordinary lime glass. The alkalies were not estimated separately, and no formula can therefore be given for it.

XXVI. This is an ordinary lead-alkali glass, containing considerable quantities both of potash and soda. After deducting ferric oxide, alumina, and manganese, its composition may be represented by the empirical formula

$$43SiO_2, 5PbO, 5Na_2O, 3K_2O.$$

	Found.	Calculated.
SiO_2	59·60	60·18
PbO	26·44	26·00
Na_2O..............	7·44	7·23
K_2O	6·50	6·57
	99·98	99·98

XXVII. This glass is composed of silica, lead oxide, and sodium oxide, and is free from potassium. Allowing for the small amount of ferric oxide and alumina which it contains, its composition may be expressed by the empirical formula

$$10SiO_2, 3PbO, 3Na_2O.$$

	Found.	Calculated.
SiO_2	40·87	41·24
PbO	45·33	45·98
Na_2O..............	13·80	12·78
	100	100

XXVIII. This is a barium-potash glass, free from lead, and containing only a very small amount of soda. After allowing for the

Table I.

Number of specimen.	Description of glass.	Density.	Dimensions. d = thickness of bulb. s = effective surface. r = external radius.	Resistance. Temperature, centigrade.	Resistance. Specific resistance in ohms × 10^{10}.
XXV	Lime glass.........	2·487	d = 0·128 cm. s = 174·614 sq. cm. r = 3·829 cm.	149° 116 93 72 55	0·202 1·874 11·901 89·15 531·05
XXVI	Lead glass, with potash and soda	2·99	d = 0·0663 cm. s = 188·19 sq. cm. r = 3·971 cm.	150° 140 130 101 88 66	8·535 18·64 33·59 442·70 1956·50 18034·0
XXVII	Lead-soda glass made by Messrs. Powell and Sons, London	3·552	d = 0·092 cm. s = 211·54 sq. cm. r = 4·226 cm.	142° 116 90	136·5 797·3 5249·0*
XXVIII	Barium-potash glass made by Messrs. Powell and Sons	3·11	d = 0·127 cm. s = 249·1 sq. cm. r = 4·566 cm.	138° 125 95 77	6·47 16·01 178·05 1115·50
XXIX	Lead-potash glass made by Messrs. Powell and Sons (annealed)	3·41	d = 0·086 cm. s = 295·411 sq. cm. r = 4·422 cm.		Resistance too high to measure. Certainly above 29000 at 140°
XXX	Lead-potash glass made by Messrs. Powell and Sons (unannealed)	3·34	d = 0·996 cm. s = 211·286 sq. cm. r = 4·2014 cm.	142°	1328·6 Too high to measure at lower temperatures
XXXI	Lead-soda glass made by Messrs. Powell and Sons (annealed)	3·408	d = 0·059 cm. s = 226·705 sq. cm. r = 4·3199 cm.	141° 122 102 84	4·874 20·497 102·820 515·94
XXXII	Lead-soda glass made by Messrs. Powell and Sons (unannealed)	3·36	d = 0·0985 cm. s = 213·246 sq. cm. r = 4·1921 cm.	140° 120 104 83 73	1·691 4·927 20·821 144·640 215·130

* This result at 90° is not accurate, but

Table I.

Capacity.		Chemical Composition.							
Temperature, centigrade.	Specific inductive capacity.	Silica.	Lead oxide.	Barium oxide.	Calcium oxide.	Potassium oxide.	Sodium oxide.	Ferric oxide and alumina.	Manganese (calculated to MnO).
11° 129	6·26 6·79	69·04 —	very small trace	..	7·59	19·23		2·73	1·31
10° 130	7·06 7·90	58·82	26·10	..	trace	6·42	7·35	0·43	0·81
8° 130	5·42 5·69	40·75	45·19	..	..	..	13·76	0·29	
22° 147	6·93 7·18	52·28	..	26·09	..	19·74	0·64	0·25	
18° 140	7·22 7·42	48·25	40·80	..	..	10·65	..	0·29	
18° 140	6·76 7·05	50·11	39·74	..	..	10·03	..	0·12	
20° 140	8·013 8·302	50·42	40·24	..	..	trace	8·77	0 38	
19° 130	7·376 8·44	51·46	38·94	..	..	..	9·13	0·25	

serves to show the order of the quantity.

Table II.

Number of specimen.	Dimensions. d = thickness of bulb. s = effective surface.	Date of test.	Temperature, centigrade.	Resistance. Specific resistance in ohms × 10^{10}.
XXI	.. ..	April 27, 1898	Up to 140°	Resistance too high to measure.
		Dec. 15 ,,	,,	
		July 3, 1899	,,	
XXVII	d = 0·085 cm. s = 215·15 sq. cm.	Mar. 31, 1898	138°	106·17
			107	1609·3
			90	Resistance too high to measure.
		Mar. 19, 1898	142	73·3
			119	505·35
			90	Resistance too high to measure.
		July 4, 1899	144	72·28
			115	535·9
			90	Resistance too high to measure.
XXVIII	d = 0·158 cm. s = 230·686 sq. cm.	June 7, 1898	145°	2·37
			114	23·32
			93	152·79
			72	1039·25
		Jan. 13, 1899	130	9·35
			106	61·77
			89	296·97
		July 5, 1899	142	5·045
			105	91·56
			85	461·64
XXIX	d = 0·125 cm. s = 204·306 sq. cm.	July 6, 1899	Up to 140°	Resistance too high to measure.
XXX	d = 0·1135 cm. s = 210·14 sq. cm.	July 7, 1899	140°	1777·5 Could not be measured at lower temperature.
XXXI	d = 0·0483 cm. s = 219·5 sq. cm.	July 11, 1899	136°	7·533
			100	102·04
			89	316·40
XXXII	d = 0·1438 cm. s = 208·8 sq. cm.	July 10, 1899	141°	0·8502
			110	8·175
			69	298·95

small quantities of ferric oxide, alumina, and sodium oxide, its composition may be represented by the formula

$$20SiO_2, 4BaO, 5K_2O.$$

	Found.	Calculated.
SiO_2	53·29	52·54
BaO	26·59	26·87
K_2O	20·12	20·58
	100	99·99

XXIX and XXX. Both of these glasses are from the same pot, XXIX being annealed, and XXX unannealed. Although they yielded slightly different numbers on analysis, they are essentially the same, and may be represented by one formula, viz.,

$$23SiO_2, 5PbO, 3K_2O.$$

	Found.		
	XXIX.	XXX.	Calculated.
SiO_2	48·39	50·17	49·69
PbO	40·92	39·78	40·15
K_2O	10·68	10·04	10·15
	99·99	99·99	99·99

XXXI and XXXII. These two glasses correspond closely to XXIX and XXX, soda, however, being substituted for potash. It was hoped, in preparing them, to obtain a glass closely corresponding to XXIX and XXX, soda being substituted for potash in exactly equivalent quantity; but Messrs. Powell found that in order to make the glass workable, it was necessary to add a slight excess of soda. XXXI was annealed; XXXII remained unannealed. The composition of both may be expressed by the formula

$$24SiO_2, 5PbO, 4Na_2O.$$

	Found.		
	XXXI.	XXXII.	Calculated.
SiO_2	50·70	51·7	51·37
PbO	40·47	39·12	39·77
Na_2O	8·82	9·17	8·84
	99·99	99·99	99·98

We desire, in conclusion, to express our thanks to Messrs. Powel. and Sons for their kindness in preparing glasses for us, and to Messrs. O. W. Griffith and Robert Abell for their help in the electrical and chemical experiments respectively.